Mr. Worthington speaks as if we were anxious to do away with a student's familiarity with force as a push or a pull. This shows that he does not appreciate our position.

I even venture to assert that in what he says concerning mass and inertia he is not so absolutely clear in his own mind as it is desirable for a reformer to be. May I suggest to him that the "inertia" or "inertia-reaction" of a lump or mass of matter—that which is measured in an experiment, and the only thing that can be measured in an inertia experiment—is $m\frac{dv}{dt}$; and that the coefficient of the otherwise measurable kinematic factor in this quantity is properly called "the coefficient of inertia," but is, for brevity, styled "mass," and is taken as a measure of the quantity of matter in the body, because, experimentally, it is found to be absolutely unalterable by every physical and chemical process except those which change the amount of matter in the lump. Fancy making our standard of quantity of matter depend upon the approximately determined gravitative attraction of some arbitrarily selected planet at some arbitrarily selected spot near its present surface!

Sometimes, indeed, m is briefly called merely "inertia," just as the coefficient $\frac{V - V^1}{C}$ in Ohm's law is for brevity styled "resistance"; but the full names of these quantities are "coefficient of inertia" and "coefficient of resistance," respectively. In the case of friction the full name is usually given. With junior students it is clearest to give the full names in every case; just as it is much clearer with them to avoid the misleading abbreviation specific heat, and to use the full phrase specific capacity for heat.

OLIVER J. LODGE.

Liverpool, January 14.

A Hare at Sea.

AMONG the notes published in NATURE for December 27, 1888, is an account of a hare swimming across a river; perhaps the following account of a hare taking to the sea may be of interest. In October 1887, I was a member of a shooting party staying near Auchencairn on the Kirkcudbrightshire coast, where for miles the waves of the Solway beat on red sandstone cliffs, broken here and there by small bays, where the burns run down to the sea through little glens. One day I had left the others and was standing among the seaweed-covered boulders of such a bay, when the sounds of a course reached me from a hill-side a quarter of a mile or more away, and presently I saw hare and greyhounds coming down to the shore; they ran close past where I was standing, and then to my astonishment the hare deliberately entered the water and swam out to sea.

I could not persuade the greyhounds to follow, though one was so close that, if she had done so at once, she could have caught the hare without swimming, as the latter was out of her depth directly and swam very slowly. The sun was shining very bright on the water, and it soon became very difficult to keep the hare in sight, as her head only showed now and then on the top of a wave, and about a hundred yards from shore I saw her for the last time, though I stayed about the place a long while.

This hare was perhaps hard pressed, still I could see no reason why she should not have run along the shore to the march dyke, which was close to, and where she would probably have made good her escape.

W. J. BEAUMONT.

Sandiway, Northwich, January 13.

THE ARTIFICIAL REPRODUCTION OF VOLCANIC ROCKS.[1]

ORIGINALLY, the study of the crust of the earth was purely utilitarian: it seems to have been at first forced upon man by the necessity of exploring the strata in order to extract metallic ores, constructive materials, and combustible minerals.

To anyone who glances at the history of the sciences, it becomes evident that they all owe their origin to some useful and practical aim, and that from this initial phase they have passed through a regular development: this progress, so far as geology is concerned, I shall proceed to sketch.

Man, then, commences to explore the depths of the earth in order to extract the materials which may minister to his wants. At first he works without rule; but as the miner's art is developed, method is introduced into the search for mineral wealth, and he observes the conditions under which useful minerals and rocks occur in the bosom of the earth. These observations, at first merely empirical and local, gradually become generalized, and thus lead to a recognition of some of the leading features in the architecture of our planet. On digging into the earth, it soon becomes evident that the world was not made at a single stroke, but owes its formation to a succession of epochs.

It follows, therefore, that, in order to interpret the history of the earth, and the operation of the agencies which have taken part in its formation, it is necessary to study the living world, and to investigate the present condition of our planet. In comparing the various strata of the earth with the deposits which are in course of formation under our own eyes, we realize the conditions which have presided at the formation of the stratified rocks of ancient geological periods. It is thus that, by the analysis of facts, and by induction which generalizes the observations, our knowledge of the crust of the earth enters on a new and truly scientific phase. We start by attempting to discover practical rules for the guidance of the miner, and we are gradually led to decipher the history of the earth.

In this reconstruction of the past history of our planet we are guided by a fundamental principle—namely, that the essence of the forces which have acted upon the earth has never changed. We ought, then, to seek in geological epochs for traces of only such phenomena as are of the same nature as those which we can witness to-day, and submit to direct observation.

Since geologists commenced, towards the close of the last century, to apply the inductive method to the study of the mineral masses which form the crust of the earth, to their architecture, and to the organic remains embedded in the rocks, a vast collection of documents has accumulated, bearing upon the history of our planet. During this period, Geology has made such immense progress that she need not envy the older branches of natural science.

Let us see how, in applying this analytical method and relying on induction, geology interprets the formation of the rocks. Rocks, we know, are the solid mineral masses which constitute the earth's crust. Observation teaches us to recognize two groups. The first are characterized by an arrangement in beds or strata: these are the sedimentary rocks. The second group, which does not present this stratified arrangement, comprises rocks of volcanic character, with a massive structure. These differences in the structure and composition of the two great lithological groups lead us to regard them as having been formed under special conditions, which have left their imprint upon each group.

We see the sedimentary rocks in the course of formation when we observe how detrital matter is rolled about by stream and wave, and how such waters deposit pebbles, sand, and mud upon their beds. After the death of the organisms which inhabit these waters, their skeletons or their shells become mingled with the mineral deposits, and with them build up sedimentary masses. The minerals so deposited assume, by successive accumulation, a stratified arrangement. All their constituent particles were originally isolated grains, and still retain traces of their origin: they are either the *débris* of pre-existing rocks or organic exuviæ, which, by physical and chemical processes, may become subsequently consolidated.

Let us now compare these modern sedimentary deposits, characterized by a stratified arrangement, and by the detrital nature of their constituents, with certain geological strata. We observe on continental surfaces masses of rock of geological antiquity, which offer close analogy in aspect and structure to the materials which are deposited under our very eyes by fluviatile and marine action. This comparison leads us to regard the old stratified rocks as having been formed by the operation of the same causes, and we hence consider them to be deposits of submarine or fluviatile origin. Water is therefore the agent which is everywhere at work in the formation of sedimentary or detrital masses.

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[1] A Lecture delivered in French at the Royal Institution, on Friday, May 18, 1888, by M. Alphonse Renard, LL.D., Hon.M.R.S.E., Corr.G.S., Curator of the Royal Museum, Brussels. Translated by F. W. Rudler.

The second group, of which we have specially to treat, includes the massive rocks—those which may be observed in course of formation during volcanic manifestations. The molten matter, vomited from the crater or injected into the sedimentary beds, consolidates on cooling. The constituents of the lavas are crystalline individuals developed at the expense of the surrounding magma. These crystals are not detrital, in the sense in which we have just used that term. Speaking in general terms, we may say that the eruptive masses do not present the stratified arrangement of the sedimentary rocks; but in place of the original horizontality and the regular superposition of the stratified beds, the lavas offer an appearance which indicates the thrust from below upwards, to which they were subjected during eruption. Finally, the massive rocks are destitute of organic remains.

Let us now compare the contemporary volcanic rocks with certain ancient crystalline rocks—granites, porphyries, trachytes, and basalts. We observe that these present close analogy in structure and composition to the products of active volcanoes. From the possession of these common characteristic features, we may conclude that the massive rocks, which traverse the strata, have been, like the modern lavas, injected from below, and share with them an eruptive origin.

But while we see the sedimentary rocks in course of formation under our eyes, and can closely follow the conditions which preside at their origin—the work being accomplished, so to say, in broad daylight—the eruptive masses are elaborated in the depths of the earth; their genesis is to some extent enshrouded in mystery, and our vision fails to penetrate the vast subterranean reservoirs where the molten masses are formed, and whence they are projected in volcanic eruptions.

Here the paths of direct observation are partially closed against us. Neither the finest analysis nor the strictest reasoning can supply the missing data; they are powerless to show us all the causes which are at work in the formation of the eruptive rocks.

In order to resolve our doubts, and to control and complete our observations, we therefore attempt to reproduce the volcanic rocks artificially; to form them synthetically. Armed with the results of observation which must serve as our guide, we endeavour by scientific manipulation to imitate the products of Nature. The science of the earth, previously analytical, enters thenceforth upon its final phase—that of synthetic experiment.

These attempts to imitate Nature, guided by the intelligence of man and executed by his hand, enable him, though limited in resource, to obtain results which offer analogy to that which he desires to investigate; he can direct and regulate the progress of the phenomena, can note with exactitude their relations, and can vary at will the conditions under which they arise. The knowledge acquired by observation, analysis, and reasoning, is thus, according to Bacon's expression, "tested by steel, and by the fire of experiment."

We have now indicated in broad outline the three great steps in the progress of our knowledge of the earth's crust. We have watched it at its birth, when it was limited to utilitarian ends; we have followed it later in its course, when, guided by observation and reasoning, it rose to the dignity of a science. Geology, entered now on its last phase, is transformed into an experimental science.

We shall now show, in studying the artificial reproduction of recent volcanic rocks, how powerfully the resources of the laboratory can assist the direct observation of Nature. But before explaining the methods employed in the synthesis of modern volcanic rocks, we must briefly summarize our knowledge of the constitution and formation of these volcanic masses, as derived from analysis and observation. It is to these natural lavas that our synthesis must be directed; they form the models which we must copy, and it is therefore necessary to become thoroughly acquainted with them in order that we may imitate them in their closest details.

Let us, then, recall what we know about lavas and the conditions of their formation. Without dwelling on these grand manifestations of the internal forces of the earth, or the succession of phenomena in an eruption—those formidable disturbances which shake the volcano to its very base, and eject pulverized vitreous matter and red-hot stones—we may remark that in the midst of such a cataclysm, the crater and the flanks of the mountain, rent by pressure of the matter seeking to escape, allow floods of lava to flow forth, and this matter, rolling down the mountain, slowly solidifies upon its slopes.

The chief feature of an eruption is the emission of lava or streams of molten matter escaping from the crater. We may best compare the lava, in general terms, to a glass liquefied under the influence of the high temperature which prevails beneath the solid crust of the earth. Direct observation of the temperature of the liquefied lava at the moment of its emission from the crater is surrounded by dangers which few observers dare to encounter. Hence we possess on this point only approximate observations. But certain volcanoes, where the outflow of lava is never violent, and which are in a state of moderate and permanent activity, as in the Island of Hawaii, have allowed the intrepid observer to approach sufficiently near to estimate the temperature of the molten mass. It has thus been found that the temperature varies between 1000° C. and 2000° C. But on the outflow of the lava the temperature of the surface is rapidly lowered, the liquid sheet becomes incrusted with scoria, more or less thick, beneath which the fused matter flows like a stream, having a temperature of about the melting-point of steel. It is this mantle of scoria which hinders radiation, and enables the subjacent mass to retain for a long time a certain amount of viscosity.

Further on we shall discuss the observations on the phenomena of crystallization presented by this erupted matter, still liquid or viscous, but ready to congeal. Let us, however, first study some of the essential characteristics of the structure and composition of lavas. These erupted products are in many cases vesicular and scoriaceous; while in others they appear as homogeneous vitreous masses, more or less dark-coloured, in which the naked eye fails to detect any isolated mineral. Sometimes, again, this mass is charged with minerals, more or less numerous, which seem to squeeze aside the vitreous paste which cements them together. These embedded minerals, when perfectly developed, present regular polyhedral forms, constant for each species; they are, in fact, *crystals*—that is to say, perfect individuals of the mineral world. They have drawn from the original vitreous magma the chemical elements of which they consist, and which have grouped themselves according to their affinities; just as we observe that in a liquid saturated with a salt, crystals are developed, consisting of the substance which was dissolved in the mother-liquor.

Mineralogy teaches us to determine the mineral species which crystallize in lavas; chemical analysis, in turn, furnishes us with valuable information respecting the composition of volcanic products. If we subject the eruptive rocks to chemical processes, we find that they all contain more or less combined silica, which may reach to upwards of 65 per cent. of the mass: these are the acid or light lavas. Thence we pass, by various gradations, to the basic or dense lavas, in which the proportion of silica, gradually diminishing, does not reach more than 55 or even 45 per cent. This silica does not exist in a free state in modern lavas, but is combined, in the form of silicates, with alumina, iron, lime, magnesia, potash, and soda.

In the slags of metallurgical works we find products which present close analogy to those of volcanoes, both in composition and in mode of formation. These artificial scoriæ are, like lavas, formed of silicates; and another point of resemblance between them lies in the fact that we may regard both as the scum of a metallic nucleus, of which they form the upper zones. The differences in composition result from the fact that they are derived from zones of greater or less depth.

Our knowledge of eruptive rocks came to be enriched in an unexpected manner by the application of the microscope to lithology. We need not here recall the almost marvellous results obtained by this method of investigation, inaugurated by H. C. Sorby; but we may say, in a word, that the microscopic analysis of rocks has changed the face of petrography. Let us confine our attention to some of the conceptions relating to modern volcanic rocks, as revealed by these new methods—methods which, in delicacy, in certainty, and in elegance, are unsurpassed in any other branch of natural science. Not only have they enabled us to verify and control hypotheses, but they have led to the remarkable discoveries to which I am about to refer.

The eye, assisted even by the most powerful lenses, could recognize in lavas only those minerals which appeared in rather large crystals; chemical analysis generally gave merely the composition of the total rock, and its mineralogical composition was only suspected. The intimate texture of the rock remained impenetrable; it was impossible to determine with certainty the order in which the constituents of the molten mass had solidified; neither could we trace the various states through which the crystals had passed—their germs, primordial forms, and skeletons—or the aspect of the rock at different stages of its development.

Let us now apply the microscope to the examination of a thin slice of lava, rendered transparent by polishing. The lavas, as we have said, may be compared to vitreous masses; but whilst in our artificial glasses we seek to obtain a pellucid and homogeneous product, the liquefied matter of volcanoes, when it flows forth, already contains certain differentiated products. The glass which contains these bodies may be regarded as the residue of the crystallization, whence the numerous crystalline individuals have extracted their constituent elements. In the black, brilliant, volcanic glasses, apparently opaque and destitute of crystallization, the microscope discovers a world of mineral forms. It shows us their various states of growth, and the arrest of their development consequent on the more or less rapid consolidation of the mass. It is especially in those rocks which, like obsidian, have preserved almost wholly their vitreous character, and are homogeneous to the naked eye, that we find the rudimentary crystals of curious form, representing the first step in the passage of the amorphous matter to the crystalline condition. Owing to the rapidity with which the vitreous paste consolidated, the crystals were unable to grow, and their development was sharply arrested. Hence the origin of these embryonic crystals which abound in natural glasses, and which we designate as *crystallites*. Analogous crystallites are produced in blast-furnace slags, which have close relations to the matter of lavas. Their common origin is betrayed by certain family likenesses which the microscope reveals. The slags, examined in thin sections, exhibit rudimentary crystalline forms, similar to the crystallites of volcanic glasses.

But usually the crystals have not remained in this embryonic state. If the lava has not been too rapidly cooled, the molecular movements are retained, even in a semi-liquid mass, and the paste develops crystals of minute dimensions, called *microlites*. These microscopic crystals are formed in the heart of the vitreous magma during its slow consolidation. Notwithstanding their infinite minuteness, these small polyhedra exhibit with marvellous exactitude all their specific characteristics, such as we are familiar with in much larger crystals, and which we should not expect to find in lavas. They often form, by their interlacement, a beautiful network in the paste, and give to the rock in which they are developed a *microlitic structure*.

The dimensions of these microlites, invariably microscopic, and their arrangement, prove that they may be referred to a period of disturbance; that they were formed, indeed, at a time when the lava, though still in motion, was solidifying. They separated from the magma during the very act of outflow or eruption.

Besides these microscopic crystals and these groups of crystallites, which belong to the last stage of consolidation, the lava contains also a supply of larger crystals, more fully developed, and in many cases recognizable by the naked eye. These have been formed under calmer conditions, analogous to those presented by a tranquil fluid in which crystallization is proceeding slowly. They were formed in the molten magma when it was still inclosed in the subterranean reservoirs. This slow growth is clearly proved by the formation of the crystals in concentric zones and by their size. These large crystals, existing ready formed in the lava at the time of its eruption, are surrounded by microlites or by a vitreous mass. It was after their slow development in the magma, during an intra-telluric period, that the mass in which they floated was upraised. The period of calm was succeeded by one of agitation, and the lava in its violent ejection carried forth the crystals, breaking them, corroding them, and partially fusing them. The microscope offers distinct evidence of these phenomena. We see the large crystals dislocated and their fragments dispersed, their edges rounded and eroded, and their substance invaded and penetrated by the paste.

While the physical and chemical agencies brought into play by the movement of the lava thus attack the ancient crystals to the verge of demolition, the microlites are in course of formation. This vitreous matter, in which the large crystals float, solidifies as a mass of microscopic individuals. The latter are therefore related to a second phase of crystallization: they are developed in a moving viscous magma, and their further growth is arrested by the rapid cooling which induces solidification *en masse.*

The fluidal arrangement of the microlites distinctly shows, too, that the crystalline action was contemporaneous with the movement of the lava-flow. Indeed, we see in microscopic preparations that the microlites are accumulated around the large sections of crystals, forming wavy trains and presenting the arrangement which micrographers designate as *fluidal structure*. It is marked by the orientation of these infinitely small acicular crystals. When these streams of microlites meet the large embedded crystals, they sweep round them, crowding into the spaces between the large sections, accommodating their flow to these outlines, and preserving for us the last movement of the mass at the very moment of solidification.

The microscope therefore proves that crystallization in lavas belongs to two periods: the first, anterior to the eruption, during which the large crystals already found are suspended in a mass that we may regard as entirely vitreous; and the second period, when the microlites and embryonic crystalline forms are separated, dating from the ejection or outflow, and contemporaneous with the solidification of the rock.

From these microscopic observations on the crystals of the second period, we may conclude that they are formed purely and simply by igneous action, without requiring the hypothetical temperatures and pressures formerly considered necessary, and without that absolute repose regarded as needful for the regular crystallization of minerals. We see, indeed, that the microlites are formed after the outflow, at the normal barometric pressure and at a temperature far from being as high as generally supposed, and we witness the birth of the crystals during the very flow of the lava stream. When the cooling is extremely rapid, the microlites have no time to form, and the lava can produce only crystallites.

But the microscope enables us to determine the chronology of the crystals in lava in a still more detailed manner. We have already distinguished two great periods in their history; let us now indicate in a general way how we may establish to some extent the date at which each species of the two groups is separated from the magma. Data leading to the determination of their relative age are afforded by their inclusions.

A crystal developed in a vitreous mass frequently incloses particles of the medium in which it grows. In this way certain sections under the microscope appear penetrated with vitreous grains, imprisoned in the interior of the crystals and frequently arranged along the zones of successive growth. These inclusions prove that the crystals in question were formed in a vitreous mass, liquefied by heat. In other cases the inclusions are mineral species in the form of microlites; and it is clear that they must have been anterior in date to the mineral in which they are inclosed. Finally, in other cases a species will mould itself around sharply defined crystals, conforming to their outlines, and filling up all the spaces between the minerals; thus showing that the crystals are of earlier origin than the surrounding mineral.

From these facts, which speak for themselves, we have been able to draw up chronological lists indicating the relative date of crystallization of each species of the two great periods. I will not stop to cite these lists, but we shall soon see how the law which governs the successive formation of the crystals, and their relative age, is evolved from synthetic experiments.

I have traced in broad outline the history of a lava, but have sketched only a few of the details which modern researches on lithological phenomena have developed with such startling reality: nevertheless, what we have seen is sufficient to show in a striking manner the power of analysis when supported by reasoning. I think I am not wrong in saying that from this point of view the study of a lava presents one of the finest examples of the application of the inductive method to the natural sciences. We hardly know whether to admire most the analytical processes, or the subtlety of observation, or the logical method by which the observed phenomena have been brought into connection.

Microscopic analysis, powerful as a method of investigation, has enabled us to trace with close exactitude the progress of crystallization in a rock where the unaided eye could discover only an indistinct and uniform mass; to penetrate into this marvellous tissue of volcanic products, where millions of polyhedra occur within the volume of a cubic centimetre; to determine with mathematical precision the nature of each of these infinitely small bodies; to track them to their birth, and follow them throughout their development, tracing all the modifications to which they have been subjected under the influence of physical and chemical agents.

Nevertheless, to the conscientious and modest investigator, how much still remains unknown in connection with the history of volcanic products, though the field seems so narrow, and has already been so well worked! What problems remain unsolved, even by the most refined observation! But when observation can no longer aid us, when we have exhausted all the resources of this method of investigation, there yet remains the method of synthetic experiment. This forms one step more on the road which leads to a perfect knowledge of the phenomena, and may conduct us to their definite solution. But, in order that synthetic operations may attain this end, they must be directed with due intelligence and design.

One of the essential conditions of a geological synthesis, as Sénarmont remarked, is, that each of the artificial operations should be compatible with all the circumstances traceable in the products of the natural operation. The slags and scoriæ of our furnaces, which, as we have shown, are related to certain natural products, are, it is true, the results of synthesis, but synthesis made at haphazard; and thus, notwithstanding their high scientific interest, cannot be placed on the same level with the synthesis of which I am about to speak, where the experimentalist, bearing steadily in view the problem which he desires to solve, attempts to realize in the laboratory the identical conditions which have surrounded the formation of the natural products which he wishes to imitate.

In logical order, the synthetic methods follow the progress of observation and of analysis. But even in the very infancy of geology there were certain powerful minds which foresaw, with the glance of genius, the part which experiment was destined to play in that science. Buffon proved by experiment that granite and the principal crystalline rocks are fusible, and that they were transformed by fusion into a vitreous mass. Some years later, Spallanzani performed an extensive series of experiments on the fusion of lavas, in order to overcome the prejudices which prevailed respecting the cause of the heat of eruptive matter.

But it is especially to Sir James Hall that belongs the honour of having, by his celebrated researches, introduced experiment into geology. He demonstrated its application in a masterly manner, and was led to sound generalizations. We have here to notice in Hall's researches only those which relate to the synthesis of rocks. About the time when Spallanzani studied, by laboratory methods, the conditions of the formation of lavas, the illustrious Scottish geologist was busy fusing the eruptive rocks in a vessel of graphite: he observed that the product of this fusion, if cooled rapidly, became an amorphous vitreous mass, while, if cooled more slowly, crystals were formed. James Hall had already observed by experiment the capital fact for future synthesis that, in order to regenerate the crystals of a rock which has been fused, it is necessary to maintain the glass obtained by the fusion at an elevated temperature, but yet a temperature always inferior to that required for the fusion of the rock. During this process, certain minerals crystallize. These facts may be paralleled with the phenomena which lavas display when their temperature is lowered after their emission.

Towards the commencement of this century, Gregory Watt directed his researches in the same direction. He experimented on masses of basalt, 700 pounds in weight: these he fused, and allowed to cool during eight days beneath a layer of charcoal, which was slowly consumed. During this prolonged *recuit*, spherulitic concretions of fibro-radiated texture, 6 centimetres in diameter, separated in the opaque black glass resulting from the fusion: finally, the glass passed into a stony condition, assumed a granular structure, and became charged with very thin crystalline lamellæ. At the same time, its magnetism was increased, while its density rose from 2·743 to 2·949.

One conclusion from the researches of Watt, which are closely related to those of Hall, is, that crystallization may occur during the period when the fused matter commences to solidify.

At the time when the road to the synthesis of rocks was being thus opened up, analysis and the methods of investigation had not attained to the perfection which they enjoy at the present day; on the other hand, the prejudices which held sway in the infancy of geology increased the obstacles, and these were not surmounted until half a century later. We need not be detained here by the brilliant period of mineral synthesis which followed close on the development of chemistry and mineralogy. It is sufficient to cite the names of Ebelmen, Rose, Mitscherlich, and Sénarmont, to recall those remarkable results in the artifical reproduction of minerals. But the researches of these *savants* related chiefly to the synthesis of isolated species, and not to rocks which are aggregates of mineral species. Speaking generally, it may be said that their researches were essentially mineralogical, and bore but subordinately on lithology. Nevertheless, the researches of these skilful experimentalists shed much light upon geological problems. They also show us that, as the mineral sciences progress, we are led to seek, by experimental methods, the most complete interpretation of the phenomena of Nature. Finally, in 1866, Daubrée led the way to the reproduction of crystalline rocks by simple fusion. This is the method which has been since taken up and developed by MM. Fouqué and Michel Lévy. The researches of Daubrée, to which we refer, are those in which he sought to reproduce by fusion certain meteoric stones characterized by the absence of a felspathic element. By fusing lherzolite, a terrestrial rock which approximates in composition to certain meteorites, he succeeded in obtaining products which, in the details of their structure and composition, resembled the cosmical types which he desired to imitate.

While this eminent geologist thus foreshadowed the researches which some years afterwards shed so brilliant a lustre upon the geological laboratory of the Collège de France, the synthetic methods were still encumbered by hypotheses. It is true we had no longer to struggle against the assumed influence of mysterious forces; but it was held that the reproduction of geological phenomena in the laboratory would be possible only if we had an infinite duration of time at our disposal, and dealt with temperatures and masses far beyond those which we could hope to command in the laboratory. It was still supposed that the mineral associations in Nature were governed by other laws than those which determined the combinations produced by the chemist. Such prejudices would certainly not have hindered Daubrée from proceeding in the path in which he so bravely took the first step by his synthesis of meteorites; for he, indeed, is one of those whose works have largely contributed to banish such prejudices from the realms of geology; but the methods of analysis which then existed did not allow us to probe the nature of the rocks to their very base, and to compare their intimate structure with that of the products of synthesis. Our laboratories were not then in possession of the apparatus by means of which we can command those very high temperatures, maintained during a prolonged period, which such experiments require.

The great improvements in the construction of apparatus, and the application of the microscope to lithology, have at length enabled us to successfully attempt the reproduction of all the modern volcanic rocks. Two French *savants*, MM. Fouqué and Michel Lévy, who introduced into their country the study of micrographic lithology, began in 1877 a series of synthetic experiments destined to be memorable in the annals of science. One of them had already acquired a just reputation by his remarkable researches on volcanic phenomena, carried on in various classical regions; he was familar with all the secrets of the chemical analysis of minerals—a department which he had enriched by the most ingenious and useful methods. The other, prepared by the severe studies of the high French schools, had undertaken, with brilliant success, the examination of minerals by their optical properties: he had carried exact methods into micrography, far beyond what others had done, and he was known by his researches on the eruptive rocks of the older series.

By their joint labours, MM. Fouqué and Lévy have to some extent systematized and co-ordinated the facts relative to the chronological succession of the crystals in eruptive rocks, and have discovered many of the details which we have already noticed in explaining the results of the analyses of lavas. It is to this happy association of talent, to this fruitful collaboration, that we owe those beautiful discoveries which have given such celebrity to the laboratory of the Collège de France, and to which it is an honour for me to render homage before an audience ever ready to welcome scientific progress, and in a place where the immortal Faraday once brought forward, with generous enthusiasm, the admirable researches of Ebelmen in connection with mineral synthesis.

We have already indicated the data upon which these *savants* relied in their researches: they are furnished by chemical and mineralogical analysis. One point, however, not yet touched upon, lies at the base of their general procedure. Theory would predict that the most ancient crystals in an igneous rock should be those which are the least fusible. And this, speaking in general terms, is really what we observe: the minerals of the first period of crystallization are those which occupy the lowest degrees in the scale of fusibility. The constituent mineral species of lavas have appeared at successive periods, as the temperature diminished, according to their relative degrees of fusibility. These facts, proved in detail by microscopic analysis, served as the point of departure in the experiments of MM. Fouqué and Lévy. Their process rests, morever, upon a fact which James Hall foresaw: namely, that the fusion of a rock produces a glass which is more easily fusible than any of the constituent crystalline species of the rock. Now, if we fuse a natural aggregate of minerals and subject the glass produced by this fusion to a series of diminishing temperatures, but always higher than that of the fusing-point of the vitreous mass, the minerals, which can crystallize from this magma should make their appearance one after another, and the less fusible should be the first to separate. These crystals will be united and moulded round by those of which the fusibility is higher, and which will appear in turn as the temperature decreases. Without dwelling on the technical details of the apparatus, it suffices to say that, by aid of the furnaces and bellows, which MM. Fouqué and Lévy employ in their syntheses, we can obtain all degrees of temperature, from a dull red to a dazzling white heat, and can maintain a given temperature constant for an unlimited period.

Into the furnace we introduce a platinum crucible of a capacity of about 20 cubic centimetres, containing the mixture of mineral substances which by fusion and *recuit* are to be transformed into the rock. First, by aid of special arrangements, we subject it for a long time to a glowing white heat, and the mixture is converted into a glass. By regulating the admission of gas and air, and by uncovering the furnace, the temperature is lowered to an orange heat—the fusing-point of steel. By raising the crucible in the furnace, the temperature falls to a cherry-red heat—the melting-point of copper. Finally, if the crucible be completely removed from the furnace, it can still be maintained at a temperature at which copper would fuse with difficulty.

We have thus indicated the broad lines of the operation. These are the successive *recuits* at diminishing temperatures which cause the crystals to be formed in sequence, commencing with the least fusible, and which enable us to impart to the fused matter the texture and the mineral composition of volcanic products.

We proceed to illustrate by examples the method of lithological synthesis. Let us first explain the manipulations for the reproduction of one of the rocks which plays the principal part in the eruptions of Vesuvius—*leucotephrite*. This rock is composed of leucite, labrador-felspar, and augite.

A mixture is formed of silica, alumina, lime, ferric oxide, potash, and soda, corresponding to one part of augite, four of labrador-felspar, and eight of leucite. This mixture is introduced into the crucible, and fused at a glowing white heat to a homogeneous glass. After fusion, the temperature is lowered, and the vitreous mass is exposed for forty-eight hours to the temperature of fused steel. During this first phase, crystals of leucite separate. They evidently correspond to the first period of consolidation in eruptive rocks.

The matter is then subjected during another forty-eight hours to the temperature of fused copper. All the mass, the residue from which the crystals of leucite first separated, is now transformed into microliths of augite and labrador-felspar, with octahedra of magnetite and picotite.

Let us now compare microscopic preparations of the synthetical product of this double *recuit* with those of the natural lava. Not only have the same minerals been reproduced by this dry fusion, but the order of their appearance and the proportion of the constituent species are identical; and their analogy may be pursued even to the details of the crystallographic forms. The leucite, in large crystals, offers all the features of this mineral in the Vesuvian lavas; and around these crystals are grouped the microlites of the second period—the augite and labrador. Finally, as in the natural rock, the leucite contains inclusions of magnetic iron-ore and picotite, which are the most ancient minerals in the rock.

As a second example, let us take the synthesis of *basalt*—one of the most widely-spread types of rock in the volcanic series, and one which, so far as its origin is concerned, has been the subject of numerous hypotheses. It is known that basalt is composed essentially of three minerals—olivine, augite, and labrador-felspar. The olivine in the natural rock appears in crystals of the first consolidation.

As in the case of the leucotephrite, so here, we form a mixture of the chemical constituents, or of the powdered minerals, corresponding to the mean composition of a basalt rich in olivine. Such a mixture is composed of three parts of olivine, two of augite, and three of labrador. This is first transformed into a homogeneous black glass. During forty-eight hours it is maintained at a white heat. If, after this *recuit* at a high temperature, we examine a thin section of the glass, we observe large crystals of olivine. These are as yet embedded in a vitreous mass, in which small octahedra of massicotite and picotite are isolated, as also a few crystals of augite.

It remains now to produce the microlites of the second consolidation, by which the crystals of olivine developed during the first phase ought to be surrounded. To produce these, the mass is maintained at a cherry-red heat for forty-eight hours. After this *recuit* we obtain a paste composed of microlites of labrador and augite, with magnetite and a vitreous substance which is the residue of the crystallization. We have therefore, in this second phase, reproduced the microlithic structure. These manipulations produce basalts which we can scarcely distinguish from the natural rocks, and thus a few grammes of a substance skilfully manipulated furnish us with the most convincing proof of the purely igneous formation of this rock.

We could go on explainng these remarkable series of experiments by MM. Fouqué and Lévy, in the same way as we have dealt with the two preceding syntheses. All the contemporary eruptive rocks have thus been reproduced: andesites, labradorites, basalts, limburgites, nephelinites, tephrites, leucite rocks, peridotites, and labradorites with ophitic structure. We will, however, confine ourselves, as a last example, to those processes by which they have succeeded in directly explaining, by means of synthesis, the eruptive phenomena of the older periods of the globe.

There are certain ancient crystalline rocks, common in the Pyrenees, which are known as *ophites*. The period at which they were formed, and their mode of origin, had not been definitively established, when in 1877 M. Lévy showed that they were eruptive and that they exhibited under the microscope a remarkable structure which he termed the "ophitic structure," the felspar being surrounded by very large plates of augite. It seemed, then, that the ophitic rocks were igneous rocks, in which the cooling had been more slow than in the ordinary rocks of modern eruptions. It was therefore necessary, in attempting to reproduce the ophitic type by synthesis, to cause the augite to crystallize during a phase sharply separated from that in which the felspar was reproduced; and, moreover, to give to the augite sufficient time to crystallize in large plates. For this purpose, a mixture of one part of anorthite and two of augite was submitted, after fusion, to a first *recuit*, in which it was maintained for forty-eight hours at the melting-point of steel: under these conditions the anorthite separated. A second *recuit* of the same duration as the first, but at the fusing-point of copper, led to the crystallization of the augite in large plates, which were moulded round the felspathic element, and to which were added small octahedra of magnetite and picotite. By this remarkable synthesis the eruptive origin of the ophites, and the cause of their structure, were established beyond all doubt.

It is thus seen how synthesis succeeds in explaining the genesis of rocks, and in settling those discussions which until recently were rife with respect to the principal crystalline types of modern date; those relating, for example, to basalt—a rock in whose formation it was argued that water played an important part. Now, the broad conclusion to be drawn from these experiments is that basalt, and, indeed, modern volcanic rocks in general, have been formed by a fusion purely igneous.

But by the side of these magnificent results the *savants* have had to record many fruitless experiments. It is useful to recall these by way of example, as they serve to indicate the paths to be avoided if we would attain success. These failures circumscribe the field of future experiment, and mark the limits within which hypotheses should have play. They demonstrate, moreover, that the rocks which we have not succeeded in forming synthetically by our methods must have been formed under different conditions from those which prevail in the formation of modern volcanic products. This conclusion' to which observation and analysis had already pointed, without, however, precisely defining the cause, is thus confirmed by the failure of our synthetic researches. If synthesis has succeeded in reproducing all kinds of lava from modern eruptions, it has failed to imitate those rocks which are no longer formed in contemporary eruptions. It may be said, generally, that up to the present time all the acid rocks have withstood our synthetic efforts, and those which contain among their constituent minerals, quartz, mica, orthoclase, and hornblende.

The processes of Nature involve no occult forces, and it may be that by combining those means which are already at our disposal, and in modifying their application, we may be permitted to witness the production of those rocks which have hitherto eluded our efforts. Such a hope is based on the results already attained, which we may regard as only the presage of others perhaps still more surprising. The failures of the past prepare for the conquests of the morrow.

In this rapid review of the progress of lithological synthesis, I have endeavoured to show the high scientific value of the researches instituted in the geological laboratory of the Collège de France. I could also have explained the successful syntheses, not less remarkable, of minerals and meteorites made by these experimentalists or by their pupils, among whom M. Bourgeois occupies a special position. But I must limit myself; and, indeed, what I have said is sufficient to show how their methods have advanced our knowledge in a domain to which access had previously appeared shut against investigation.

Wherever the experimental method has hitherto carried its torch, it has brilliantly illuminated the most striking phenomena in the science of the earth. It suffices to mention the name of Daubrée, the direct descendant of the illustrious geologists of the Scottish school, to indicate the extent of the field of the mineral sciences already explored by the method of experiment. It has been successfully applied to the interpretation of metalliferous deposits and of metamorphic rocks, and to the study of the fractures and deformation of the earth's crust, of the schistosity of rocks, and of certain features in mountain structure.

Geology, after having passed through the successive phases of observation and analysis, has therefore entered upon that of experiment and synthesis, in which it strives to imitate the creative power of Nature, thus crowning the scientific edifice by processes which allow us to catch a glimpse of the operation of causes the knowledge of which is the final aim of physical and natural science. It was this crowning of the work which Leibnitz foresaw when he wrote, two centuries ago:—"He will perform, in our opinion, an important work, who shall carefully compare the products extracted from the depths of the earth with those of the laboratory; for then will be brought vividly before our eyes the striking resemblance which subsists between the productions of Nature and those of Art. Although the Creator, inexhaustible in resource, has at command divers means of effecting His will, it nevertheless pleases Him to maintain a constancy in the midst of the variety of His works; and it is already a great step towards a knowledge of things to have discovered even one means of producing them; for Nature is only Art on a large scale."

SOME RECENT ADVANCES IN THE THEORY OF CRYSTAL-STRUCTURE.

THE growth of modern theories concerning the structure of crystals is perhaps not so closely followed by English chemists as might be expected from the inherent interest of the subject, in spite of the attention which is now devoted to all questions of atomic and molecular arrangement in space.

It is in the morphology of crystals that the geometrical arrangement of the atoms or molecules (in the solid) finds, if anywhere, a geometrical expression, and yet little or no account is taken of this subject in textbooks of chemistry or physics, so that it is difficult for the student to discover what views are held by modern authors. Moreover, crystallographic observations and theories are generally published in journals specially devoted to mineralogy which are not easily accessible to all who are interested in such questions.

It seems, therefore, advisable to draw attention to the progress which has recently been made in the theory of crystal-structure, and more especially to papers by Prof. Sohncke, of Munich, published in Groth's *Zeitschrift für Krystallographie und Mineralogie*, a journal which is a complete storehouse of information relating to the study of crystals.

Sohncke's theory, which was published in 1879,[1] has now emerged from the purifying fire of recent criticism in an emended form in which perhaps it will more readily excite the interest of chemists.

In order to make it clear in what respects the theory of Sohncke in its latest form differs from those which have been previously advanced it will be necessary to give a brief sketch of the theory of Bravais, of which Sohncke's system is an extension.

The Abbé Haüy,[1] having found that all crystals of the same substance may be reduced by cleavage to the same solid figure, whatever their external form, argued that the cleavage solid has the form of the ultimate particles into which any crystal may in imagination be separated by repeated subdivision, and that this is therefore the form of the structural unit: it is not, of course, necessary or even probable that the latter should be identical with the chemical molecule. Hence a crystal is to be regarded as constructed of polyhedral particles, having the form of the cleavage fragment, placed beside one another in parallel positions. A crystal of salt, for example, which naturally cleaves parallel to the faces of the cube, is constructed of cubic particles.

Upon the relative dimensions of the structural unit depends the form assumed by the crystals of a given substance.

It will be found that this theory not only accounts for the existence of cleavage, but further defines the faces which may occur upon crystals of a substance having a given cleavage figure; for, if once it is assumed that a crystal-face is formed by a series of the particles whose centres lie in a plane, it follows that all such planes obey the well-known law which governs the relative positions of crystal-faces.

A natural advance was made from the theory of Haüy, without detracting from its generality, by supposing each polyhedral particle in Haüy's system to be condensed into a point at its centre of mass, so that the positions of the molecules, and therefore of the crystalline planes, remain the same as before; but the space occupied by a crystal is now filled, not by a continuous structure resembling brickwork, but by a system of separate points.

It will be found that in such a system of points, if the straight line joining any pair be produced indefinitely in both directions, it will carry particles of the system at equal intervals along its entire length; in other words, all the structural molecules of a crystal must lie at equal distances from each other along straight lines. The interval between particles along one straight line will in general be different from those along another, but the molecular intervals along parallel straight lines will always be the same.

Bravais,[2] therefore, following in the steps of Delafosse and Frankenheim, treated the subject as a geometrical problem, and inquired what are the possible ways in which a system of points may be arranged in space so as to lie at equal distances along straight lines—in other words, so as to constitute what may be called a *solid network* (*assemblage*, *Raumgitter*).

The geometrical nature of a network may be best realized as follows. Take any pair ($O\,C_1$) of points in space, draw a straight line through them, and place points at equal distances along its entire length ($C_2, C_3, \ldots$); such a line may be called a *thread* of points (*rangée*). Parallel to this line, and at any distance from it, place a second thread of points ($A_1\,a_1$), identical with the first in all respects; in the plane containing these two threads place a series of similar equidistant parallel threads ($A_2\,a_2$, &c.) in such positions that the points in successive threads lie at equal intervals upon straight lines whose direction ($O\,A_1$) is determined by the points upon the first two threads. Such a system of points lying in one plane may be called a *web* (*réseau*). Now, parallel to this plane, and at any distance from it, place a second web ($B_1\,b_1$), identical with the first.

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[1] "Entwickelung einer Theorie der Krystallstruktur." (Leipzig.)

[1] "Traité de Cristallographie." (Paris, 1822.)

[2] "Études cristallographiques." (Paris, 1866.)